United States nuclear weapons, 2025

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The United States has embarked on a wide-ranging nuclear modernization program that will ultimately see every nuclear delivery system replaced with newer versions over the coming decades. In this issue of the Nuclear Notebook, we estimate that the United States maintains a stockpile of approximately 3,700 warheads—an unchanged estimate from the previous year. Of these, only about 1,770 warheads are deployed, while approximately 1,930 are held in reserve. Additionally, approximately 1,477 retired warheads are awaiting dismantlement, giving a total inventory of approximately 5,177 nuclear warheads. Of the approximately 1,770 warheads that are deployed, 400 are on land-based intercontinental ballistic missiles, roughly 970 are on submarine-launched ballistic missiles, 300 are at bomber bases in the United States, and approximately 100 tactical bombs are at European bases. The Nuclear Notebook is researched and written by the staff of the Federation of American Scientists' Nuclear Information Project: director Hans M. Kristensen, associate director Matt Korda, and senior research associates Eliana Johns and Mackenzie Knight.

This article is freely available in PDF format in the Bulletin of the Atomic Scientists' *digital magazine (published by Taylor & Francis) at this link. To cite this article, please use the following citation, adapted to the appropriate citation style: Hans M. Kristensen, Matt Korda, Eliana Johns, and Mackenzie Knight. 2025. "United States nuclear weapons, 2025."* Bulletin of the Atomic Scientists*, 81(1): 53–79.*
DOI: https://doi.org/10.1080/00963402.2024.2441624

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As of January 2025, we estimate that the US Department of Defense maintained an estimated stockpile of approximately 3,700 nuclear warheads for delivery by ballistic missiles and aircraft. Most of the warheads in the stockpile are not deployed but rather stored for potential upload onto missiles and aircraft as necessary. We estimate that approximately 1,770 warheads are currently deployed, of which roughly 1,370 strategic warheads are deployed on ballistic missiles and another 300 at strategic bomber bases in the United States. An additional 100 tactical bombs are deployed at air bases in Europe. The remaining warheads—approximately 1,930—are in storage as a so-called "hedge" against technical or geopolitical surprises. Several hundred of those warheads are scheduled to be retired before 2030 (see Table 1).

Table 1. United States nuclear forces, 2025.

Type/Designation	No. of launchers	Year deployed	Warheads x yield (kilotons)	Warheads (total available)[a]
ICBMs				
LGM-30 G Minuteman III				
Mk-12A	200	1979	1–3 W78 × 335 (MIRV)	600[b]
Mk-21/SERV	200	2006[c]	1 W87 × 300	200[d]
Total	**400**[e]			**800**[f]
SLBMs				
UGM-133A Trident II D5/LE	14/280[g]			
Mk-4A		2008[h]	1–8 W76–1 × 90 (MIRV)	1,511[i]
Mk-4A		2019	1–2 W76–2 × 8 (MIRV)[j]	25[k]
Mk-5		1990	1–8 W88 × 455 (MIRV)	384
Total	**14/280**			**1,920**[l]
Bombers				
B-52 h Stratofortress	76/46[m]	1961	8-20 ALCM/W80–1 × 5–150	500
B-2A Spirit	19/19[n]	1994	Up to 16 B61–7 × 10–360/-11 × 400/-12 × 0.3–50	280
Total	**95/65**[o]			**780**[p]
Total strategic forces			**3,500**	
Nonstrategic forces				
F-35A, F-15E, F-16C/D, NATO DCA	n/a	1979	1–5 B61–3/-4/-12 bombs x 0.3–170[q]	200
Total				**200**[r]
Total stockpile				**3,700**
Deployed				1,770[s]
Reserve (hedge and spares)				1,930
Retired, awaiting dismantlement				**1,477**
Total Inventory				**5,177**

Table 1. United States nuclear forces, 2025. (Click to display full size.)

While the majority of the United States' warheads comprise the Department of Defense's military stockpile, retired warheads under the custody of the Department of Energy awaiting dismantlement constitute a "significant fraction" of the United States' total warhead inventory (US Department of Energy 2024b, F-6). Dismantlement operations include the disassembly of retired weapons into component parts that are then assigned for reuse, storage, surveillance, or for additional disassembly and subsequent disposition (US Department of Energy 2023b, 2–11).

The pace of warhead dismantlement has slowed significantly in recent years: While the United States dismantled on average more than 1,000 warheads per year during the 1990s, in 2023 it dismantled only 69 warheads—the lowest number since the 1990s (National Nuclear Security Administration 2024a). According to the Department of Energy, "[d]ismantlement rates are affected by many factors, including weapon system complexity, availability of qualified personnel, equipment, facilities, logistics, policy and directives, and legislative requirements" (US Department of Energy 2024a, 2–14). The US Department of Energy stated in April 2023 that it "was on pace to complete the dismantlement of all warheads retired before Fiscal Year (FY) 2009 [Sep. 2008] by the end of FY 2022 [Aug. 2022]" but that the COVID-19 pandemic "delayed the dismantlement of a small number of these retired warheads until after FY 2022 [Aug. 2022]" (US Department of Energy 2023a, 2–12). The FY 2025 Stockpile Stewardship and Management Plan reported that the Pantex Plant—where all warhead assembly and disassembly activities take place—surpassed its FY 2023 dismantlement goals and increased its staffing to support its FY 2024 commitments. It also reportedly completed the dismantlement of all remaining W84 warheads that had previously been in the queue—a process that took approximately 15 years from start to finish for the entire stockpile of 400 warheads (Kristensen 2010; US Department of Energy 2024a, 2–14).

Warhead dismantlement and disposition is an important process for the National Nuclear Security Administration (NNSA), as the new warheads that the United States is building rely on critical components from warheads that are currently awaiting retirement and eventual dismantlement. For example, the new B61–12 and B61–13 gravity bombs utilize modified versions of the physics packages used in the current B61–4 and B61–7 gravity bombs, respectively.

Based on these timelines and recent dismantlement rates, we estimate that the United States possesses approximately 1,477 retired—but still intact—warheads awaiting dismantlement, giving a total estimated US inventory of approximately 5,177 warheads.

The US nuclear weapons are thought to be stored at an estimated 24 geographical locations in 11 US states and five European countries (Kristensen and Korda 2019, 124). The number of locations will increase over the next decade as nuclear storage capacity is added to three bomber bases. The location with the most nuclear weapons by far is the large Kirtland Underground Munitions and Maintenance Storage Complex south of Albuquerque, New Mexico. Most of the weapons in this location are retired weapons awaiting dismantlement at the Pantex Plant in Texas. The state with the second-largest inventory is Washington, which is home to the Strategic Weapons Facility Pacific and the ballistic missile submarines at Naval Submarine Base Kitsap. The submarines operating from this base carry more deployed nuclear weapons than any other base in the United States.

The United States is embarking on an ambitious plan to overhaul its nuclear weapons arsenal over the next three decades, though the modernization effort has faced significant political, financial, and logistical challenges. Based on the Congressional Budget Office's 2017 estimate, the effort will cost $1.2 trillion (Congressional Budget Office 2017). Notably, although the estimate accounts for inflation, other estimates forecast that the total cost will be closer to $1.7 trillion (Arms Control Association 2017). Whatever the actual price tag will be, historical trends and chronic delays to the modernization program indicate that it is likely to increase over time.

In addition to the ongoing warhead modernization programs, the United States is also starting to consider how follow-on warhead programs will ultimately shape the US force posture. For example, in 2024 the Nuclear Weapons Council approved two studies on non-ballistic reentry vehicles and hard and deeply buried targets (US Department of Energy 2024a, 5–14).

In 2023, multiple governmental advisory commissions published reports intended to influence the US nuclear posture. The US State Department's International Security Advisory Board report on "Deterrence in a World of Nuclear Multipolarity" advised the United States to pursue competition with Russia and China "without accelerating arms race instability or risking runaway competition" (US State Department 2023b). In contrast, the Congressionally-mandated report on "America's Strategic Posture," published in October 2023, included a broad range of recommendations for the United States to prepare to increase the number of deployed warheads, as well as to scale up its production capacity of bombers, air-launched cruise missiles, ballistic missile submarines, non-strategic nuclear forces, and warheads (US Strategic Posture Commission 2023). It also called for the United States to deploy multiple warheads on land-based intercontinental ballistic missiles (ICBMs) and consider adding road-mobile ICBMs to its arsenal.

While neither report represents official US government policy, the Strategic Posture Commission report's status as a bipartisan document has been particularly useful for nuclear advocates to push for additional nuclear weapons (Heritage Foundation 2023; Hudson Institute 2023; Thropp 2023). Overall, nuclear politics in the United States is trending toward the right, and it appears likely that the second Trump administration will attempt to adopt some of the more hawkish policies included in the Strategic Posture Commission and other non-governmental nuclear advisory papers.

Research methodology and confidence

The analyses and estimates made in the Nuclear Notebook are derived from a combination of open sources: (1) state-originating data (e.g. government statements, declassified documents, budgetary information, military parades, and treaty disclosure data); (2) non-state-originating data (e.g. media reports, think tank analyses, and industry publications); and (3) commercial satellite imagery. Because each of these sources provides different and limited information that is subject to varying degrees of uncertainty, we crosscheck each data point by using multiple sources and supplementing them with private conversations with officials whenever possible.

Collecting and analyzing accurate information about US nuclear forces is significantly less challenging than for most other countries, as the United States is the most transparent nuclear-armed state. To that end, we assess that the estimates included in this Nuclear Notebook come with a relatively high degree of confidence.

The United States is one of only a small handful of countries that has published data about the exact size of its nuclear stockpile. While this data is not released annually and largely depends upon the whims of the administration in power, as recently as 2024, the US government responded positively to a declassification request made by the Federation of American Scientists, disclosing the size of the stockpile through September 2023 and the number of annually dismantled warheads (National Nuclear Security Administration 2024a). The disclosure revealed that as of September 2023, the United States' nuclear stockpile included 3,748 warheads—40 more than our previous estimate of 3,708 (National Nuclear Security Administration 2024a, Kristensen et al. 2024). We estimate that the stockpile will continue to decline slightly over the next decade as modernization programs consolidate the remaining warheads.

In addition, the United States also releases highly detailed assessments and reports relating to its nuclear forces, including the NNSA's Stockpile Stewardship and Management Plan, budgetary justification documents, and environmental impact statements, among others. Government officials are also legally responsive to checks and balances, particularly Congress, which regularly asks for programmatic and budgetary updates on nuclear weapons programs. These checks are supported by robust watchdog, civil society, and media organizations, including government-funded agencies like the Government Accountability Office and the Congressional Budget Office, investigative journalists, and nongovernmental organizations that report on and critique government programs and plans.

We generally rely on official sources and images—as well as commercially or freely available satellite imagery—to analyze the United States' nuclear arsenal and, whenever possible, try to corroborate the credibility of any unofficial claims with multiple sources. Satellite imagery can be particularly useful in monitoring construction at military facilities, as well as identifying which types of missiles, vessels, or aircraft are present at bases. In certain cases, useful imagery about nuclear systems can also be obtained through social media posts—both from military and civilian accounts—and can be used in conjunction with satellite imagery for more concrete analysis.

Finally, the United States is party to a bilateral arms control treaty with Russia—the New Strategic Arms Reduction Treaty (New START)—that until recently produced biannual datasets of deployed strategic nuclear forces. Russia suspended its participation in New START in February 2023, and in response the United States has not published any aggregate numbers since May 2023, when it declared that it had 1,419 warheads attributed to 662 deployed ballistic missiles and heavy bombers as of March 1, 2023 (US State Department 2023a). The 2022 Nuclear Posture Review stated that "[t]he United States will field and maintain strategic nuclear delivery systems and deployed weapons in compliance with New START Treaty central limits as long as the Treaty remains in force" (US Department of Defense 2022a, 20); however, it remains unclear whether the incoming Trump administration will adhere to this plan.

The New START warhead numbers reported by the US State Department differ from the estimates presented in this Nuclear Notebook for several reasons. The New START counting rules artificially attribute one warhead to each deployed bomber, even though US bombers do not carry nuclear weapons under normal circumstances. Moreover, the Nuclear Notebook counts as deployed all weapons stored at bomber bases that can quickly be loaded onto the aircraft, as well as nonstrategic nuclear weapons at air bases in Europe. This provides a more realistic picture of the status of US-deployed nuclear forces than the treaty's artificial counting rules.

The New START treaty has proven useful so far in keeping a lid on both countries' deployed strategic forces. When the treaty expires in February 2026—and if it is not followed by a new agreement, which seems to be the likely case, given recent trends—then both the United States and Russia could potentially increase their deployed nuclear arsenals by uploading several hundreds of stored reserve warheads onto their launchers. Additionally, if the treaty's verification and data-exchange arrangements are not replaced, both countries will lose important information about each other's nuclear forces. Until the treaty's so-called "suspension," the United States and Russia had completed a combined 328 on-site inspections and exchanged 25,017 notifications (US State Department 2022).

Nuclear planning and nuclear exercises

Since 1994, each presidential administration has conducted a review of the US nuclear posture that describes the administration's guidance for US nuclear policy and strategy. The three most recent Nuclear Posture Reviews (NPR)—published in 2010, 2018, and 2022—have remained relatively consistent. Like previous NPRs, the Biden administration's review said the United States reserved the right to use nuclear weapons under "extreme circumstances to defend the vital interests of the United States or its allies and partners" and rejected policies of nuclear "no-first-use" or "sole purpose" (US Department of Defense 2022a, 9). Even so, the 2022 NPR noted that the United States "retain[s] the goal of moving toward a sole purpose declaration and [it] will work with [its] Allies and partners to identify concrete steps that would allow [it] to do so" (9) (For a detailed analysis of the 2022 NPR, see Kristensen and Korda 2022).

The most significant change made in Biden's 2022 NPR was the walking back of two Trump-era commitments. Specifically, Biden's review attempted to cancel the proposed nuclear sea-launched cruise missile (SLCM-N) and continued with the retirement of the B83–1 gravity bomb.

In addition to the Nuclear Posture Review, the nuclear arsenal and its role are shaped by plans and exercises that create the strike plans and practice how to carry them out.

The current strategic nuclear war plan—OPLAN 8010–12—consists of "a family of plans" directed against four identified adversaries: Russia, China, North Korea, and Iran. Known as "Strategic Deterrence and Force Employment," OPLAN 8010–12 first entered into effect in July 2012 in response to the operational order Global Citadel. The plan is designed to be flexible enough to absorb normal changes to the posture as they emerge, including those flowing from the NPR. Several updates have been made since 2012, but more substantial updates will trigger the publication of what is formally considered a "change." The April 2019 change refocused the plan toward "great power competition," incorporated a new cyber plan, and reportedly blurred the line between nuclear and conventional attacks by "fully incorporat[ing] non-nuclear weapons as an equal player" (Arkin and Ambinder 2022a, 2022b).

OPLAN 8010–12 also "emphasizes escalation control designed to end hostilities and resolve the conflict at the lowest practicable level" by developing "readily executable and adaptively planned response options to de-escalate, defend against, or defeat hostile adversary actions" (US Strategic Command 2012). While not new, these passages are notable, not least because the Trump administration's NPR criticized Russia for an alleged willingness to use nuclear weapons in a similar manner, as part of a so-called "escalate-to-deescalate" strategy.

OPLAN 8010–12 is a whole-of-government plan that includes the full spectrum of national power to affect potential adversaries. This integration of nuclear and conventional kinetic and non-kinetic strategic capabilities into one overall plan is a significant change from the strategic war plan of the Cold War that was almost entirely nuclear, extremely large-scale, and "massively destructive" (Hyten 2017). The US Department of Defense's 2022 Nuclear Posture Review and 2023 Strategy for Countering Weapons of Mass Destruction reaffirm the importance of flexibility, integration, and tailored plans (US Department of Defense 2023a).

The Nuclear Employment Strategy published by the Trump administration in 2020 reiterated this objective: "If deterrence fails, the United States will strive to end any conflict at the lowest level of damage possible and on the best achievable terms for the United States, and its allies, and partners. One of the means of achieving this is to respond in a manner intended to restore deterrence. To this end, elements of US nuclear forces are intended to provide limited, flexible, and graduated response options. Such options demonstrate the resolve, and the restraint, necessary for changing an adversary's decision calculus regarding further escalation" (US Department of Defense 2020, 2). This objective is not just directed at nuclear attacks, as the 2018 NPR called for "expanding" US nuclear options against "non-nuclear strategic attacks."

In March 2024, the Biden administration issued new nuclear employment guidance, superseding the previous administration's guidance. Press reports claimed the new guidance shifted focus to China (Sanger 2024); however, an unclassified version of the guidance released in November shows that Russia remains the "acute threat" (US Department of Defense 2024c, 1). The guidance does direct "that the United States be able to deter Russia, the PRC, and the DPRK simultaneously in peacetime, crisis, and conflict" (US Department of Defense 2024d, 2). But, for years, the plan has been to deter those countries simultaneously, although the guidance does not require achieving all war objectives against Russia and China at the same time.

To practice and fine-tune the strike plans resulting from the guidance, the armed forces regularly conduct several nuclear-related exercises. For example, US Strategic Command's exercise Global Lightning in March 2024 was linked to the exercise Austere Challenge held in Europe (US European Command 2024). This was followed by Air Force Global Strike Command's exercise Prairie Vigilance in April, an annual nuclear bomber exercise at Minot Air Force Base in North Dakota, which practiced the 5th Bomb Wing's B-52 strategic readiness and nuclear generation operations (Minot Air Force Base Public

Affairs 2024). The Vigilance exercises normally lead up to Strategic Command's annual week-long Global Thunder large-scale exercise toward the end of the year that "provides training opportunities that exercise all US Strategic Command mission areas, with a specific focus on nuclear readiness" (US Strategic Command 2021a). Global Thunder was most recently held on October 18–24, 2024 at Minot AFB (Air Force Global Strike Command Public Affairs 2024a).

These developments have been influenced by Russia's invasions of Ukraine in 2014 and again in 2022. One example of this involves the expansion of bomber operations and updates to strike plans. Very quickly after the Russian annexation of Crimea, the US Strategic Command (US STRATCOM) increased the role of nuclear bombers in support of the US European Command (Breedlove 2015), which, in 2016, put into effect a new standing war plan for the first time since the Cold War (Scapparotti 2017). Before 2018, the bomber operations were called the Bomber Assurance and Deterrence missions but have been redesigned as Bomber Task Force missions to bring a stronger offensive capability to the forward bases and make those forward deployments more capable. Whereas the mission of Bomber Assurance and Deterrence was to train with allies and have a visible presence to deter Russia, the mission of the Bomber Task Force is to move a fully combat-ready bomber force into the European theater (Wrightsman 2019). These changes are evident in the increasing number—and more provocative nature—of bomber operations over Europe, in some cases very close to the Russian border (Kristensen 2022a). For example, in March 2024, a nuclear-capable B-52—part of a pair operating over Eastern Europe—flew into the Gulf of Finland toward St. Petersburg all the way to Russian airspace before it abruptly turned south over the Baltic States (Kristensen 2024d). Two months later, two B-52s from a Bomber Task Force deployed to RAF Fairford in the United Kingdom flew over the Baltics, and at one point were within a dozen kilometers of Kaliningrad (Gordon 2024). Additionally, in July 2024, two B-52s flew through Finnish airspace for the first time before landing in Romania to start the first B-52 deployment in that country (US Air Forces in Europe – Air Forces Africa 2024). While these two particular aircraft were not nuclear-capable, another nuclear-capable B-52 flew east of Svalbard Island, south toward the Russia missile submarine base on the Kola Peninsula, and further over northeastern Norway and Finland in November 2024 on its way to Europe (Kristensen 2024a).

These changes are important indications of how US strategy—including nuclear operations—has changed in response to deteriorating East-West relations and the new "great power competition" and "strategic competition" strategy promoted by the Trump and Biden administrations, respectively. In recent years, there has also been an increase in the mix of B-52 and B-2 deployments to Australia. In August 2024, for example, a bomber task force of three B-2 bombers deployed to Royal Australian Air Force Base Amberley, Australia to "demonstrate interoperability and bolster our collective ability to support a free and open Indo-Pacific" (Pike 2024). Additionally, in November 2024, six B-52 bombers deployed to Al Udeid Air Base in Qatar (at least five of six were nuclear-capable), likely as a signal to Iran amid the ongoing conflict in the Middle East (Kristensen 2024b). They also illustrate a growing integration of nuclear and conventional capabilities, as reflected in the new strategic war plan. B-52 Bomber Task Force deployments typically include a mix of nuclear-capable aircraft and aircraft that have been converted to conventional-only missions. For instance, in March 2024, a B-52 and a B-1 conducted a rare flyover of Stockholm while accompanied by Swedish Air Force Gripens fighter aircraft in celebration of Sweden joining NATO (Hadley 2024). US strategic bombers now routinely operate over Swedish territory. Integration of nuclear and conventional bombers into the same task force can potentially have implications for crisis stability, misunderstandings, and the risk of nuclear escalation because it could result in overreactions and misperceptions about whether it is a conventional or nuclear signal.

Additionally, since 2019, US bombers have been practicing what is known as an "agile combat employment" strategy by which all bombers "hopscotch" to a larger number of widely dispersed smaller airfields—including airfields in Canada—in the event of a crisis. This strategy is intended to increase the number of aimpoints for a potential adversary seeking to destroy the US bomber force, therefore raising the ante for an adversary to attempt such a strike and increasing the force's survivability if it does (Arkin and Ambinder 2022a). However, this doctrine can be challenged if an adversary has enough long-range weapons to target several locations simultaneously, especially

those with tankers, or if its ability to find and engage targets is faster than the Air Force's ability to launch an attack (Blaser 2024).

Land-based ballistic missiles

The US Air Force (USAF) operates 400 silo-based Minuteman III ICBMs and keeps "warm" another 50 silos to load stored missiles if necessary, for a total of 450 silos. Land-based missile silos are divided into three wings: the 90th Missile Wing at F. E. Warren Air Force Base in Colorado, Nebraska, and Wyoming; the 91st Missile Wing at Minot Air Force Base in North Dakota; and the 341st Missile Wing at Malmstrom Air Force Base in Montana. Each wing has three squadrons, each with 50 minuteman III silos collectively controlled by five launch control centers. We estimate there are up to 800 warheads assigned to the ICBM force, of which about half are deployed (see Table 1).

The 400 deployed Minuteman IIIs carry one warhead each, either a 300-kiloton W87/Mk21 or a 335-kiloton W78/Mk12A. ICBMs equipped with the W78/Mk12A, however, could technically be uploaded to carry two or three independently targetable warheads each, for a total of 800 warheads available for the ICBM force. The USAF occasionally test-launches Minuteman III missiles with unarmed multiple independently targetable reentry vehicles (MIRVs) to maintain and signal the capability to reequip some of the Minuteman III missiles with additional reentry vehicles, if desired.

The Air Force conducts several Minuteman III flight tests each year. These are long-planned tests, and the Air Force consistently states that they are not scheduled in response to any external events. The Air Force conducted two successful test launches in 2024 of a Minuteman III with one reentry vehicle (Air Force Global Strike Command Public Affairs 2024b), and one additional launch in November 2024 with multiple reentry vehicles (Air Force Global Strike Command Public Affairs 2024c).

Although the Minuteman III was initially deployed in 1970, it has been modernized several times, including in 2015, when the missiles completed a multibillion-dollar, decade-long modernization program to extend their service life until 2030. The modernized Minuteman III missiles were referred to by Air Force personnel as "basically new missiles except for the shell" (Pampe 2012).

Part of the ongoing ICBM modernization program involves upgrades to the Mk21 reentry vehicles' arming, fuzing, and firing system at a total procurement cost of nearly $1 billion (US Department of Defense 2023b), 135; US Department of Defense 2023c). The publicly stated purpose of this refurbishment is to extend the vehicles' service lives, but the effort appears to also involve adding a "burst height compensation" to enhance the targeting effectiveness of the warheads (Postol 2014). The first production unit was approved in March 2024, and Sandia National Laboratory reported that the modernized fuze was successfully tested for the first time as part of a Minuteman III ICBM test launch on June 4, 2024. With these milestone achievements, Sandia reported that all "indicators look positive for the program to move into its production phase" (Deshler 2024; Sandia National Laboratories 2024). These modernization efforts complement a similar fuze upgrade underway to the Navy's W76–1/Mk4A warhead.

Early acquisition activities for a new ICBM reentry vehicle—the Mk21A—began in FY24, and the program is expected to enter the Engineering & Manufacturing Development (EMD) phase in FY25 (US Air Force 2024). Lockheed Martin was awarded a sole-source contract in October 2023 amounting to just under $1 billion for the engineering and manufacturing of the new reentry vehicle (US Department of Defense 2023d). The Mk21A will be integrated into the new Sentinel ICBM to bolster its payload suite and will be capable of carrying the new W87–1 warhead currently in development and future warheads (US Air Force 2024, 569). The Air Force plans to begin delivering the new reentry vehicle in FY32 and estimates the total cost for the reentry vehicle to be $4.05 billion (US Air Force 2024).

The Air Force plans to purchase a total of 659 Sentinel missiles—400 of which would be deployed, while the remainder will be used for test launches and as spares (Capaccio 2020). Non-governmental experts, including those conducting Department of Defense-sponsored research, have questioned the Pentagon's procurement process and lack of transparency regarding its decision to pursue the Sentinel option over other potential deployment and basing options (Dalton et al. 2022, 4). Moreover, it is unclear why an enhancement of ICBM capabilities would be necessary for the United States.

For instance, any such enhancements would not mitigate the inherent challenges associated with launch-on-warning, risky territorial overflights, or silo vulnerabilities to environmental catastrophes or conventional counterforce strikes (Korda 2021). Additionally, even if adversarial missile defenses improved significantly, the ability to evade missile defenses lies with the payload—not the missile itself. By the time an adversary's interceptor would be able to engage a US ICBM in its midcourse phase of flight, the ICBM would already have shed its boosters, deployed its penetration aids, and be guided solely by its reentry vehicle—which can be independently upgraded as necessary. For this reason, it is not readily apparent why the US Air Force would require its ICBMs to have capabilities beyond the current generation of Minuteman III missiles; the Air Force has yet to publicly explain why.

The development of the Sentinel has also been marked by a series of controversial industry contracts, starting with the awarding of a $13.3 billion sole-source contract to Northrop Grumman in 2020 to complete the engineering and manufacturing development stage (For a more detailed summary of the Sentinel's procurement timeline, see Korda 2021). There have been warnings about program cost projection overruns for years: the Sentinel program was projected in 2020 to cost $95.8 billion, an increase from a preliminary $85 billion Pentagon estimate in 2016. In July 2023, the US Congressional Budget Office estimated that the cost of acquiring and maintaining the Sentinel would total approximately $118 billion over the 2023–2032 period—approximately $20 billion more than the Congressional Budget Office had previously estimated for the 2019–2028 period, and $36 billion more than the 2021–2030 period (Congressional Budget Office 2019, 2021, 2023a). But in early 2024, the Air Force notified Congress of a two-year delay in the schedule and an estimated 37-percent increase from the current cost target to around $130 billion (Tirpak 2024a). These amounts do not include the costs for the new Sentinel warhead—the W87–1—which is projected to cost up to $14.8 billion, or the plutonium pit production that the US Air Force and US Strategic Command say is needed to build the warheads (Government Accountability Office 2020).

The schedule and extreme cost overruns for the Sentinel program incurred a critical breach of the Nunn-McCurdy Act, requiring the Secretary of Defense to conduct a root-cause analysis and renewed cost assessment of the program (Knight 2024b). On July 8, 2024, the Department of Defense announced the results of its Nunn-McCurdy review, revealing an even higher projected cost for the Sentinel program than reported at the time of the breach at $141 billion and an expected delay of "several years" (US Department of Defense 2024a). Despite these overruns, the Pentagon certified the Sentinel program to continue (US Department of Defense 2024a). Per the requirements of the Nunn-McCurdy Act, the program's Milestone B approval was revoked, and it must be restructured to address the cause of the cost growth and achieve new milestone approval before taking any contract action (Congressional Research Service 2016; US Department of Defense 2024a). Andrew Hunter, Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics clarified that while the cost of the missile itself has increased, challenges with supporting infrastructure is the significant driver of the cost and schedule overruns (Tirpak 2024a). In addition to an entirely new missile, the Sentinel program includes renovating all 450 launch facilities, constructing new missile alert facilities, new command and control facilities and systems, and new launch centers, and establishing over 3,000 miles of new utility corridors—not to mention new training sites and curriculum for USAF personnel (Air Force Global Strike Command 2024). Many of the delays are results of staffing shortfalls, clearance delays, IT infrastructure challenges, and trouble with supply chains on the part of Northrop Grumman (Government Accountability Office 2023a, 88).

According to a USAF program report published in 2020, the Air Force must deploy 20 new Sentinel missiles with legacy reentry vehicles and warheads to achieve initial operating capability, scheduled for FY29 (Sirota 2020). However, the reported several-year schedule delay indicates that the program might not reach initial operating capability until 2032 or later. The Department of Defense has previously indicated that a two-year delay could lower the force structure by at least 30 missiles—which raises the question of whether some of the Minuteman III ICBMs will have to be life-extended regardless or if the US force structure will dip below the congressionally mandated requirement of 400 deployed ICBMs (Korda and White 2021).

Program officials had originally announced that the first Sentinel prototype would conduct a test flight by the end of 2023, but this schedule has been delayed and is now planned for 2026 (Bartolomei 2021; Congressional Research Service 2024a). The first three in a series of static firing tests were completed in March 2023 and March 2024 to assess the individual stages of the Sentinel's three-stage propulsion system (Air Force Nuclear Weapons Center Public Affairs 2023, 2024a, 2024b). Northrop Grumman also conducted a series of "shroud fly-off and missile modal tests" in early 2024 to evaluate the "forward and aft sections" of the Sentinel (Northrop Grumman 2024a). Sentinel's EMD phase includes plans to construct two test launch sites at Vandenberg Space Force Base in California (US Air Force 2023a). Satellite imagery from 2024 shows ongoing construction at one of the launch sites to upgrade the site to accommodate the Sentinel test flight program (see Figure 1).

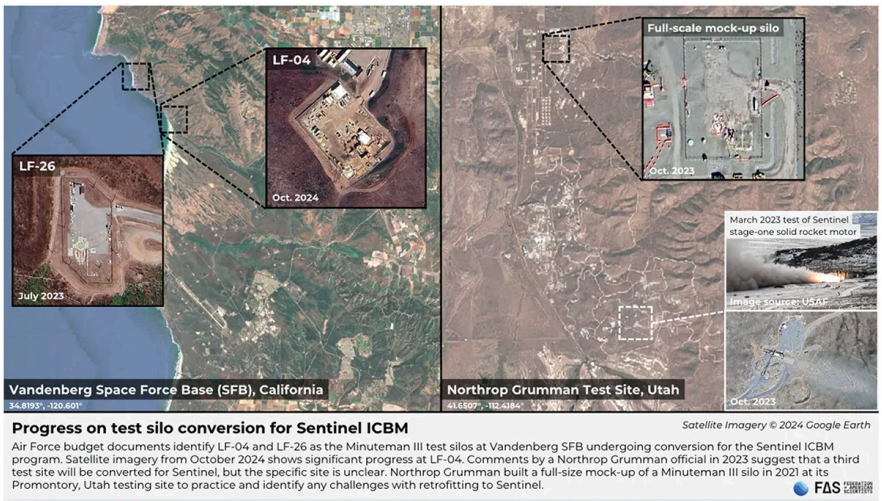

Figure 1. Progress on test silo conversion for sentinel ICBM. (Credit: Federation of American Scientists/Google Earth)

According to the US Air Force, the new Sentinel missile will meet existing user requirements but will have the adaptability and flexibility to be upgraded throughout its lifecycle and will have a greater range than the current Minuteman III (US Air Force 2016). Still, it is unlikely that the Sentinel will have enough range to target countries like China, North Korea, and Iran without over-flying Russia.

The Sentinel missile will be able to carry multiple warheads, possibly up to two per missile. The Air Force initially planned to equip the Sentinel with life-extended versions of the existing W78 (the modified version of which was known as Interoperable Warhead 1) and W87 warheads. However, in 2018, the Air Force and the NNSA canceled the upgrades and instead proposed a Modification Program to replace the W78 and eventually the W87 with a new warhead known as the W87–1. This new warhead will use a W87-like plutonium pit along with "a well-tested IHE [Insensitive High Explosive] primary design" and will be incorporated into the new Mk21A reentry vehicle (US Department of Energy 2018b). The Weapons Development Cost Report for the W87 modernization program lists the total estimated cost to be up to $15.9 million, not including the costs associated with the production of the new plutonium pits (National Nuclear Security Administration 2023, 8–31).

As required by the FY18 National Defense Authorization Act, the NNSA has set an ambitious course of action for producing at least 80 plutonium pits per year by 2030 to meet the Sentinel's planned deployment schedule. However, due to the agency's consistent inability to meet project deadlines and its lack of a latent large-scale plutonium production capability, the NNSA notified Congress in 2021 of what independent analysts have long predicted—that the agency will not be able to meet the 80-pit requirement (Demarest 2021; Government Accountability Office 2020; Institute for Defense Analyses 2019). To come as close to the annual pit production requirement as possible, the Savannah River Plutonium Processing Facility has been tasked with producing 50 of the plutonium pits while the other 30 will be produced at Los Alamos National Laboratory. A repurposed, never-completed, Mixed Fuel Oxide Fuel Fabrication facility at the Savannah River Site was originally scheduled to come online in 2030 to support the goal of 50 pits per year, but the date of completion was extended to between 2032 and 2035 (National Nuclear Security Administration

2021). The NNSA will likely face further obstacles to carrying out its pit production program as a US federal judge ruled in September 2024 that the Department of Energy (DOE) and the NNSA violated the National Environmental Policy Act (NEPA) by failing to conduct a sufficient environmental impact assessment of their two-site pit production plan (Guzmán 2024).

The W87–1 program completed its Weapon Design Cost Report and entered Phase 6.3 for development engineering in FY23, and its deployment is expected in the early 2030s (US Department of Energy 2024a). Due to the expected deployment timeline for the W87–1, the NNSA reported in 2023 that the Sentinel would be initially fielded with a modified version of the existing W87 known as the W87–0 (National Nuclear Security Administration 2023, 1–6). Despite the Sentinel program's several-year schedule delay pushing its expected deployment to coincide with that of the W87–1, a September 2024 DOE and NNSA report to Congress reaffirms the plan to field the missiles initially with the W87–0 (US Department of Energy 2024a). The NNSA announced in October 2024 the completion at Los Alamos of the first production unit of a plutonium pit for the W87–1 program (National Nuclear Security Administration 2024b).

The Air Force is faced with a tight construction schedule for the deployment of the Sentinel. Each launch facility is expected to take 10 months to upgrade, while each missile alert facility will take approximately 16 months (US Air Force 2023b). The Air Force intends to upgrade all 450 launch facilities, demolish all 45 missile alert facilities, reconstruct 24 of them, and build 45 communication support buildings and 24 new launch centers (US Air Force 2023b).

Since each missile alert facility is currently responsible for a group of 10 launch facilities, this could indicate that each missile alert facility may eventually be responsible for up to 18 or 19 launch facilities once the Sentinel becomes operational (Korda 2020). Once these upgrades begin, several launch facilities will be out of operation at any given time, which means the Air Force will not be able to maintain the congressionally mandated minimum of 400 operational ICBMs during the construction program. As a result, the 2023 Congressional Strategic Posture Commission recommended the Air Force deploy more than one warhead on some of the ICBMs to maintain the current warhead level (US Strategic Posture Commission 2023). This may not be necessary, however, as the Senate included an exception to the requirement in the FY25 National Defense Authorization Act (NDAA) Bill for "facilitating the transition from the LGM-30 G Minuteman III intercontinental ballistic missile to the LGM-35A Sentinel intercontinental ballistic missile" (2024).

Construction for the Sentinel program began in 2023 at F.E. Warren Air Force Base, where the first Sentinel deployments will take place. Sentinel construction and deployment will then take place at Malmstrom Air Force Base and finally at Minot Air Force Base (Air Force Global Strike Command 2024). Anticipated construction timelines may shift due to delays and restructuring following the program's breach of the Nunn-McCurdy Act.

As the Sentinel missile gets deployed, the Minuteman III missiles will be removed from their silos and temporarily stored at their respective host bases before being transported to Hill Air Force Base, the Utah Test and Training Range, or Camp Navajo in Arizona. The rocket motors will eventually be destroyed at the Utah Test and Training Range, while non-motor components will be decommissioned at Hill Air Force Base. To that end, new storage igloos will be constructed at Hill Air Force Base and Utah Test and Training Range (US Air Force 2020). The last Minuteman III ICBM is scheduled to be replaced in 2052 (Huser 2024).

The three ICBM bases will also receive new training, storage, and maintenance facilities as well as upgrades to their Weapons Storage Areas. The first base to receive this upgrade is F. E. Warren, where substantial construction began in spring 2020 on the new underground Weapons Storage and Maintenance Facility (Kristensen 2020a). The CEO of Fluor Corp, the company contracted to build the facility, announced in August 2024 that the facility was "substantially complete" (US Air Force 2019b; Refinitiv 2024). Commercial satellite imagery from September appears to confirm the announcement. A groundbreaking ceremony for Malmstrom Air Force Base's new Weapons Generation Facility was held in March 2024, and construction is visible on satellite imagery (Rhynes 2024) (see Figure 2). Construction of a new Missile-Handling and Storage Facility and Transporter Storage Facility also appears to have begun at F. E. Warren. The Senate's FY25 NDAA Bill, once passed, would authorize

over $1.5 billion for Sentinel-related construction at F.E. Warren, including for land acquisition, new utility corridors, and a consolidated maintenance facility. For Malmstrom, the bill authorizes approximately $250 million for the Weapons Generation Facility and a Sentinel commercial entrance and control facility (2024).

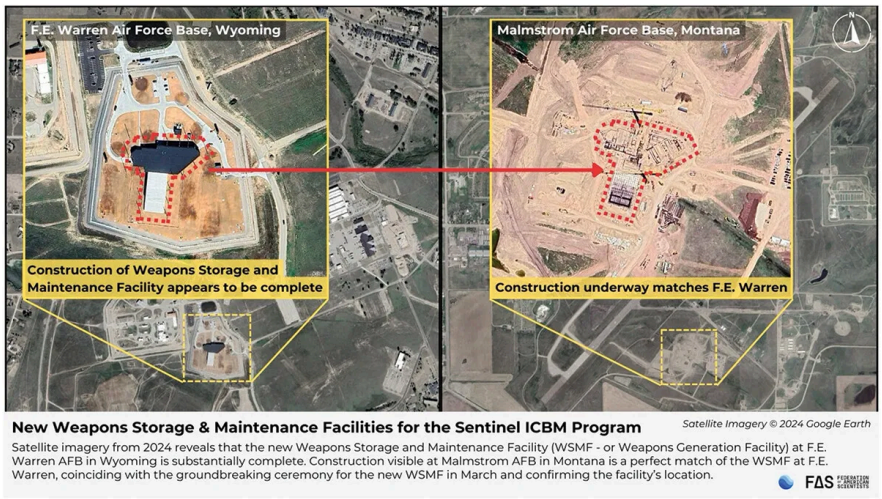

Figure 2. New weapons storage and maintenance facilities for the Sentinel ICBM program. (Credit: Federation of American Scientists/Google Earth)

Nuclear-powered ballistic missile submarines

The US Navy operates a fleet of 14 *Ohio*-class ballistic missile submarines (SSBNs), of which eight operate in the Pacific from their base near Bangor, Washington, and six operate in the Atlantic from their base at Kings Bay, Georgia. For years the submarine fleet has been rotationally undergoing a lengthy reactor refueling overhaul to extend each boat's lifespan; as the last overhaul was completed in February 2023, all 14 boats could now potentially be deployed until 2027 when the first *Ohio*-class submarine is expected to retire (PSNS & IMF Public Affairs 2023; US Navy 2019). But because operational submarines undergo minor repairs at times, the actual number at sea at any given time is usually closer to eight or 10. Four or five of those are thought to be on "hard alert" in their designated patrol areas, while another four or five boats could be brought to full alert status in hours or days.

The boats

Design of the next generation of ballistic missile submarines, known as the *Columbia*-class, is well underway. This new class is scheduled to begin replacing the current *Ohio*-class ballistic missile submarines in the late 2020s. The *Columbia*-class will be 2,000 tons heavier than the *Ohio*-class but will be equipped with 16 missile tubes rather than its predecessor's 20. The *Columbia*-class submarine program, which is expected to account for approximately one-fifth of the budget of Navy's entire shipbuilding program from the mid-2020s to the mid-2030s, is projected to cost nearly $130 billion (US Department of Defense 2024b).

The lead boat in a new class is generally budgeted at a significantly higher amount than the rest of the boats, as the Navy has a longstanding practice to incorporate the entire fleet's design detail and non-recurring engineering costs into the cost of the lead boat. As a result, the Navy's fiscal 2025 budget submission estimated the procurement cost of the first *Columbia*-class SSBN—the *USS District of Columbia* (SSBN-826)—at approximately $15.2 billion, followed by $9.3 billion for the second boat (Congressional Research Service 2024b, 9). Construction of the lead boat began on October 1, 2020—the first day of FY 2021, the keel was laid down in June 2022, and the boat passed its 50 percent construction completion metric in August 2024 (US Navy 2022; Parrella 2024). Full construction on the second—*USS Wisconsin* (SSBN-827)—began in October 2023 and as of September 2024 was 14 percent complete (US Department of Defense (2024b); Parrella 2024). Serial production for the remainder of the fleet is expected to begin in FY 2026 (Parrella 2024).

Certain elements of construction were originally delayed due to the COVID-19 pandemic, but after several years of full-scale construction, the Navy continues to face delays due to challenges with design, materials, and quality of work on

the lead submarine (Eckstein 2020; Government Accountability Office 2023b, 2024a). Even though the *Columbia* program is the top procurement priority for the Navy, an April 2024 review led by the Secretary of the Navy concluded that the lead boat of the *Columbia*-class would likely face a 12 to 16-month delay due to these factors (US Navy 2024a). This would result in the delivery of the lead boat in October 2028 at the earliest. Sea trials are expected to last three years, with the first deterrence patrol planned for 2031.

A September 2024 Government Accountability Office (GAO) report concluded that this estimated delay "will be difficult for the *Columbia* class program to fully correct," given that "the lead submarine is entering a period of construction that involves additional risks that are likely to contribute to cost and schedule growth" (Government Accountability Office 2024a, 12).

The same GAO report concluded that likely cost overruns would be more than six times higher than the lead contractor's estimates, and almost five times more than the Navy's estimates. "As a result," the GAO noted, "the government could be responsible for hundreds of millions of dollars in additional construction costs for the lead submarine … To recover from existing schedule delays, the shipbuilders would need to perform at levels of efficiency they have yet to demonstrate" (Government Accountability Office 2024a, 13–14).

The *Columbia*-class submarines are expected to be significantly quieter than the current *Ohio*-class fleet. This is because a new electric-drive propulsion train will turn each boat's propeller with an electric motor instead of louder, mechanical gears. Additionally, the components of an electric-drive propulsion train can be distributed around the boat, increasing the system's resilience, and lowering the chances that a single weapon could disable the entire drive system (Congressional Research Service 2000, 20). The Navy has never built a nuclear-powered submarine with electric-drive propulsion before, which could create technical delays for a program that is already on a very tight production schedule. The *Columbia*-class will also include other new design elements, including an X-stern ship control system, a new missile compartment, and a new reactor that—unlike those of the *Ohio*-class SSBNs—will not require refueling during its entire life cycle (Congressional Budget Office 2023b, 26).

The Navy plans for the oldest *Ohio*-class boats to begin going offline in fiscal year 2027—starting with the *USS Henry M. Jackson* (SSBN-730)—around the same time that the first *Columbia*-class boat was originally expected to be delivered in October 2027 (Office of the Chief of Naval Operations 2024; Parrella 2024). The second *Ohio*-class boat to be decommissioned is scheduled to be the *USS Alabama* (SSBN-731) in 2028 (Office of the Chief of Naval Operations 2024). Due to the delays in *Columbia*-class construction, however, the Navy has initiated a process to life-extend up to five *Ohio*-class SSBNs—beginning with the *USS Alaska* (SSBN-732)—from their planned 42-year life spans to 45–46 years (Katz 2023; Parrella 2024). The shipbuilding plan projects that the total number of operational SSBNs will fluctuate between 14 and 12 boats while the *Ohio*-class goes offline and the *Columbia*-class comes online. Given that the *Ohio*-class retirement and *Columbia*-class production schedules are not completely aligned, this means that the total number of operational SSBNs will dip below the full complement of 12 boats for three years during the acquisition/retirement process (Congressional Research Service 2024b, 6).

Sea trials for each new boat are expected to last approximately three years, with the first *Columbia*-class deterrence patrol scheduled for 2031 (Congressional Research Service 2024b, 8) (see Figure 3).

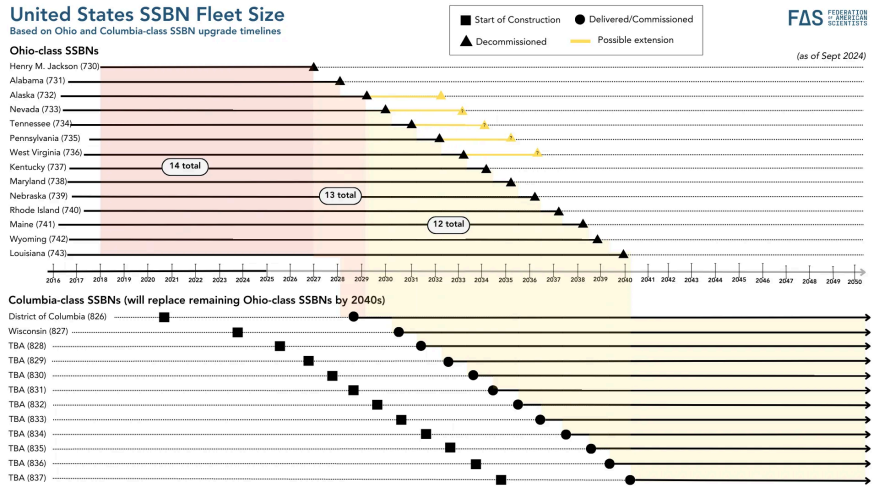

Figure 3. United States SSBN Modernization Schedule. (Credit: Federation of American Scientists)

The missiles

Each *Ohio*-class submarine can carry up to 20 Trident II D5 sea-launched ballistic missiles (SLBMs), a number reduced from 24 to meet the limits of New START. The 14 *Ohio*-class SSBNs could potentially carry up to 280 such missiles but the United States has stated that it will not deploy more than 240. The Navy has nearly completed replacing the original Trident II D5 with a life-extended and upgraded version known as Trident II D5LE (LE stands for "life-extended"). The last D5s are scheduled to be replaced with D5LEs in 2025 (Wolfe 2024).

The D5LE, which has a range of more than 12,000 kilometers, is equipped with the new Mk6 guidance system designed to "provide flexibility to support new missions" and make the missile "more accurate," according to the Navy and Draper Laboratory (Draper Laboratory 2006, Naval Surface Warfare Center 2008). According to FY25 budget documents, the D5LE has also added a hard-target kill capability and increased its payload "to the level permitted by the size of the TRIDENT submarine launch tube, thereby allowing mission capability to be achieved with fewer submarines" (US Department of Defense 2024b). This is to compensate for the fact that the United States will deploy fewer *Columbia*-class submarines than *Ohio*-class submarines and each submarine will only carry 16 missiles.

The D5LE upgrade will replace existing Trident SLBMs on British ballistic missile submarines and will also initially arm the new US *Columbia*-class and British *Dreadnought*-class ballistic missile submarines when they enter service.

Instead of building a completely new ballistic missile like the Air Force wants to do with the Sentinel ICBM, the Navy plans to do a substantial second life extension of the Trident II D5LE to ensure it can operate through 2084. While the D5LE2 missile, as it is known, represents continuity in the sense that it will still be a Trident SLBM, several older parts that no longer exist in the current supply chain will be redesigned (US Department of Defense 2024b). The D5LE2's System Requirements Review is scheduled for 2025, Preliminary Design Review for 2028, and Critical Design Review for 2032. Low-Rate Initial Production will commence in 2034, and the missile's first flight test from an SSBN is planned for 2036 (US Navy 2024b).

The D5LE2 is scheduled to enter service on the ninth *Columbia*-class SSBN beginning in FY 2039, following which it will be back-fitted to the remaining eight boats over the following decade as each boat returns to port for routine maintenance (Wolfe 2021). The final D5LE SLBM is scheduled to be retired in 2049, at which point all *Columbia*-class SSBNs in the US fleet will have been fitted with D5LE2 SLBMs (US Navy 2024b).

The warheads

Each Trident SLBM can carry up to eight nuclear warheads, but they normally carry an average of four or five warheads, for an average load-out of approximately 90 warheads per submarine. The payloads of the different missiles on a submarine are thought to vary significantly to provide maximum targeting flexibility, but all deployed submarines are thought to carry the same combination. Normally, around 950 warheads are deployed on the operational

SSBNs, although the number can be lower due to the maintenance of individual submarines. Overall, SSBN-based warheads account for approximately 70 percent of all warheads attributed to the United States' deployed strategic launchers under New START. We estimate there may be up to 1,920 warheads assigned to the SSBN fleet (although the number might be a little lower), of which roughly 950 are deployed (see Table 1).

Three warhead types are deployed on US SLBMs: the 90-kiloton enhanced W76–1, the 8-kiloton W76–2, and the 455-kiloton W88. The W76–1 is a refurbished version of the W76–0, which is being retired, apparently with a slightly lower yield but with enhanced safety features added. The Mk4A reentry body that carries the W76–1 is equipped with a new arming, fuzing, and firing unit with better targeting effectiveness than the old Mk4/W76 system (Kristensen, McKinzie, and Postol 2017). The Navy is upgrading the Mk4A to a Mk4B reentry body featuring a Shape Stable Nose Tip, which is designed to provide more consistent flight performance and improve accuracy (Wolfe 2024).

The higher-yield W88 warhead is currently undergoing a life-extension program that modernizes the arming, fuzing, and firing components, addresses nuclear safety concerns by replacing the conventional high explosives with insensitive high explosives, and will ultimately support future life-extension options (US Department of Energy 2024b, 2–11). The first production unit for the W88 Alt 370 was completed on July 1, 2021, half had been delivered by the first quarter of 2023, and production is expected to be completed in the fourth quarter of FY25 (US Department of Energy 2024b; US Department of Energy 2024a, 2–11).

The W76–2 only uses the warhead fission primary to produce a yield of about 8 kilotons. We estimate that no more than 25 were ultimately produced, and that one or two of the 20 missiles on each SSBN is armed with one or two W76–2 warheads each, while the remainder of the SLBMs will be filled with either the 90-kiloton W76–1 or the 455-kiloton W88 (Arkin and Kristensen 2020). The Biden NPR agreed "that the W76–2 [warhead] currently provides an important means to deter limited nuclear use;" however, the review left the door open for the weapon to be removed in the future, noting: "Its deterrence value will be re-evaluated as the F-35A [aircraft] and LRSO [air-launched cruise missile] are fielded, and in light of the security environment and plausible deterrence scenarios we could face in the future" (US Department of Defense 2022a, 20). This passage suggests that the W76–2 warhead could potentially be removed from service closer to the turn of the decade.

The United States is also planning to build a new SLBM warhead—the W93—which will be housed in the Navy's proposed Mk7 aeroshell (reentry body). According to the Department of Energy, its "key nuclear components will be based on currently deployed and previously tested nuclear designs and extensive stockpile component and materials experience," and that "certification of the W93 will not require additional underground nuclear explosive testing" (US Department of Energy 2024a, 1–7). The W93 is intended to initially supplement, rather than replace, the W76–1 and W88. Another new warhead is subsequently planned to eventually replace those warheads in the future. The completion of the W93's first production unit is tentatively scheduled for 2034–2036 (US Department of Energy 2022, 2–10). In September 2024, the NNSA projected the W93 program to cost $27.6 billion (in then-year dollars) over the next 25 years, which is $4.7 billion more than the NNSA's cost estimate published the previous year (US Department of Energy 2024a, 5–32; 2023b, 8–32).

US-UK collaboration

The US sea-based nuclear weapons program also supports the United Kingdom's nuclear deterrent. The missiles carried on the Royal Navy ballistic missile submarines are from the same pool of missiles carried on US SSBNs. The warhead uses the Mk4A reentry body and is thought to be a slightly modified version of the W76–1 (Kristensen 2011); the UK government calls it the "Holbrook" (UK Ministry of Defence 2015). The Royal Navy also plans to use the new Mk7 for the replacement warhead it plans to deploy on its new *Dreadnought* submarines in the future. A 2021 update to Parliament reaffirmed that "[t]he UK warhead will be integrated with the US supplied Mark 7 aeroshell to ensure it remains compatible with the Trident II D5 missile and delivered in parallel with the US W93/Mk7 warhead programme" (Government of the United Kingdom 2021). In 2023, the US Navy Director for Strategic Systems Programs clarified that, "the development of the Mk7 reentry system

to support the US W93 warhead program is also critical to the development of a next generation nuclear warhead and reentry system for the UK. The two nations are working separate but parallel warhead programs with collaboration between the two" (Wolfe 2023).

Deterrence patrols

In the past 25 years, deterrence patrol operations have changed significantly, with the annual number having declined by more than half, from 64 patrols in 1999 to between 30 and 36 annual patrols in recent years. Most submarines now conduct what are called "modified alerts," which mix deterrent patrol with exercises and occasional port visits (Kristensen 2018). While most ballistic missile submarine patrols last 77 days on average, they can be shorter or, occasionally, last significantly longer. In October 2021, for example, the *USS Alabama* (SSBN-731) completed a 132-day patrol, and in June 2014, the *USS Pennsylvania* (SSBN-735) returned to its Kitsap Naval Submarine Base in Washington after a 140-day deterrent patrol—the longest patrol ever by an *Ohio*-class ballistic missile submarine (US Strategic Command 2021b). In the Cold War years, nearly all deterrent patrols took place in the Atlantic Ocean. In contrast, more than 60 percent of deterrent patrols today normally take place in the Pacific, reflecting increased nuclear war planning against China and North Korea (Kristensen 2018).

Ballistic missile submarines normally do not visit foreign ports during patrols, but after Russia's invasion of Ukraine in 2014, the US Navy started to conduct a few foreign port visits per year to send political messages and to improve the visibility of its ballistic missile submarines. Port visits by US submarines have continued every year since, except in 2020, to locations including Scotland, Alaska, Guam, Gibraltar, and South Korea—the first time that nuclear weapons visited South Korea since the US weapons were removed from the Korean Peninsula in 1991 (Mongilio 2023). The US Navy has also increasingly released images of its SSBNs on patrol in specific theaters, including the Arabian Sea in October 2022 and the Norwegian Sea in June 2024 (US Central Command 2022; US 2024) (see Figure 4).

Figure 4. US SSBN photo-op in the Norwegian Sea. In an unprecedented (since the end of the Cold War) public display of nuclear firepower in the Norwegian Sea, the US Navy surfaced the nuclear missile submarine *USS Tennessee* (SSBN-734) off Norway in June 2024 and brought Norwegian defense officials onboard for a photo-op of the Norwegian flag on the deck. The submarines carried an estimated 20 missiles with 90 nuclear warheads. (Credit: Commander, US Submarine Forces)

Strategic bombers

The aircraft

The US Air Force currently operates a fleet of 19 B-2A bombers (all of which are nuclear-capable) and 76 B-52 h bombers (46 of which are nuclear-capable). Of the 21 original B-2 aircraft, only 19 are still operational. One bomber was lost in service in 2008, and another crashed in 2022 at Whiteman Air Force Base. In 2024, the Air Force decided that the crashed B-2 would be retired rather than fixed and returned to service (Tirpak 2024b). It is possible to distinguish between the conventional-only and nuclear-capable versions of the B-52 h due to the inclusion of externally observable features, specifically small 30-centimeter fins attached to blisters on each side of the aircraft. By observing these fins and other corresponding data sources, it is possible to develop a comprehensive and high-confidence list of which B-52 h tail numbers are

nuclear-capable and which are conventional-only (Scappatura and Tanter 2024). A third strategic bomber, the B-1B, is not nuclear-capable.

Of these bombers, we estimate that approximately 60 (18 B-2As and 42 B-52Hs) are assigned nuclear missions under US nuclear war plans, although the number of fully operational bombers at any given time is lower. The New START data from September 2022, for example, only counted 43 deployed nuclear bombers (10 B-2As and 33 B-52Hs) (US State Department 2023a). The bombers are organized into nine bomb squadrons in five bomb wings at three bases: Minot Air Force Base in North Dakota, Barksdale Air Force Base in Louisiana, and Whiteman Air Force Base in Missouri. The number of nuclear bomber bases will be increased to five once the Air Force's new strategic bomber—the B-21 Raider—enters into service (Kristensen 2017b). Given that at least 100 B-21 bombers will replace 19 B-2 bombers and all B-1 non-nuclear bombers, it seems likely that the number of nuclear-capable bombers will increase significantly.

Many of the B-21's design details remain classified; however, since it began test flights in late 2023 more details have emerged due to official and unofficial photographs and videos being released. These images have indicated that the B-21 shares several design elements with the B-2, but it is slightly smaller and has a reduced weapons capability (US Air Force 2022; Femath 2024). In addition, the B-21 has a narrower forward field of view relative to the B-2, which is likely related to the aircraft's more advanced sensors that allow the pilot to see outside the aircraft without a large windscreen (Rogoway 2024). The B-2, by comparison, has a wraparound windscreen with a tinted glass pane that is attached during nuclear missions to shield the pilot's eyes from a nuclear blast (Rogoway 2017).

It is expected that the Air Force will procure at least 100 (possibly as many as 145) of the B-21, with the latest service costs estimated at approximately $203 billion for the entire 30-year operational program, at an estimated cost of $550 million per plane in base-year 2010 dollars, which would approach nearly $800 million in 2024 dollars (Northrop Grumman 2024b). The budget and many design details of the B-21 are still secret. The B-21 is expected to enter service by 2027 to gradually replace the B-1B and B-2 bombers during the 2030s (Marrow 2024).

The B-21 will be capable of delivering the B61–12 and B61–13 guided nuclear gravity bombs and the future AGM-181 LRSO, as well as a wide range of non-nuclear weapons, including the Joint Air-to-Surface Standoff (JASSM) cruise missile.

The B-21 bombers will first be deployed at Ellsworth Air Force Base (South Dakota), followed by Whiteman Air Force Base (Missouri) and Dyess Air Force Base (Texas), in that order (Hoffman 2024). Construction at Ellsworth AFB began in 2022, and the base's new Weapons Generation Facility, which will store and maintain nuclear bombs and cruise missiles, is scheduled to be completed by February 2026 (Tirpak 2022). Ellsworth AFB is currently expected to host two B-21 squadrons (one operational squadron and one training squadron). However, according to South Dakota Sen. Mike Rounds, a second operational squadron might eventually be stationed at Ellsworth Air Force Base as well in the future (2022). To accommodate the construction at Ellsworth, 17 B-1B bombers are likely to be temporarily reassigned to Grand Forks Air Force Base for ten months, starting in January 2025 (Harpley 2024).

The conversion of the non-nuclear B-1 host bases to receive the nuclear B-21 bomber will increase the overall number of bomber bases with nuclear weapons storage facilities from two bases today (Minot AFB and Whiteman AFB) to five bases by the 2030s (Kristensen 2020b). A new Weapons Generation Facility is also under construction at Barksdale AFB, which will reinstate nuclear storage capability once complete (Knight 2024a).

In addition, a significant modernization campaign is also planned for the USAF's B-52Hs. The Air Force plans to replace the engines, electrical power generation systems, cockpit displays, and radar systems on all B-52 aircraft—an upgrade substantial enough to warrant a change in designation from the B-52 h to the B-52J and to keep the aircraft operational into the 2050s. Initial Operational Capability for the B-52Js is scheduled for February 2033 (Government Accountability Office 2024b, 69–72).

The missiles

To arm the B-52Hs and the incoming B-21, the Air Force is developing a new nuclear air-launched cruise missile (ALCM) known as the AGM-181 LRSO. It will replace the AGM-86B air-launched cruise missile in 2030.

The LRSO will arm both the 46 nuclear-capable B-52Hs and the new B-21, the first time a US stealth bomber will carry a nuclear cruise missile. The USAF plans to procure 1,087 missiles (Government Accountability Office 2024b, 81); many of these will be test and reserve missiles and so far the number of nuclear warheads for the missiles is not planned to increase. Development and production were initially projected to reach at least $4.6 billion for the missile (US Air Force 2019a) with another $10 billion for the warhead (US Department of Energy 2018a); however, that estimate has since risen to a total acquisition cost of more than $15 billion (Congressional Budget Office 2023a). Notably, the GAO reports that the cost estimates for missile production of both the Office of the Secretary of Defense and the Air Force are approximately $1.9 billion apart, indicating that the LRSO program costs have not yet stabilized (Government Accountability Office 2024b, 82).

The LRSO missile itself is expected to be entirely new, with significantly improved military capabilities compared with the ALCM, including longer range, greater accuracy, and enhanced stealth (US Department of Defense 2024c). Supporters of the LRSO argue that a nuclear cruise missile is needed to enable bombers to strike targets from well outside the range of current and future air-defense systems of potential adversaries. Proponents also argue that these missiles are needed to provide US leaders with flexible strike options in limited regional scenarios. However, critics argue that conventional cruise missiles, such as the extended-range version of the Joint Air-to-Surface Standoff Missile, can currently provide standoff strike capability—in which weapons can engage targets from a distance where attacking personnel are outside the range of defensive weapons—and that other nuclear weapons would be sufficient to hold the targets at risk. The conventional Extended-Range Joint Air-to-Surface Standoff Missile is now an integral part of US Strategic Command's strategic war plan.

The warheads

Each B-2 can carry up to 16 nuclear bombs (the B61–7, B61–11, and B61–12 gravity bombs), and each B-52 h can carry up to 20 air-launched cruise missiles (the AGM-86B). B-52 h bombers are no longer assigned gravity bombs (Kristensen 2017a). An estimated 780 nuclear weapons, including approximately 500 air-launched cruise missiles, are assigned to the bombers, but only about 300 weapons are thought to be deployed at bomber bases (see Table 1). The estimated remaining 480 bomber weapons are thought to be in central storage at the large Kirtland Underground Munitions Maintenance and Storage Complex outside Albuquerque, New Mexico.

The Department of Energy is designing and producing modified and new warheads for delivery by US Air Force strategic delivery systems. One of these —the W80–4—is planned to be a modified version of the W80–1 that is currently used in the existing ALCM. The W80–4 will eventually be carried by the LRSO when it is fielded—the first warhead designed for use with a new missile in over three decades. The NNSA authorized the production engineering phase (Phase 6.4) for the W80–4 in March 2023, and the warhead is expected to reach 90 percent design maturity in late 2025 (Government Accountability Office 2024b, 82). The First Production Unit of the W80–4 is scheduled for delivery in September 2027 (US Department of Energy 2023c), and the production of the warhead is scheduled to be completed in FY 2031 (Leone 2022).

In addition to the W80–4, two new gravity bombs—the B61–12 and B61–13—are currently being produced. The B61–12 is the United States' first guided, standoff nuclear gravity bomb, and uses a modified version of the warhead used in the current B61–4 gravity bomb, which has a maximum yield of approximately 50 kilotons and several lower-yield options. However, it will be equipped with a guided tail kit to increase accuracy and standoff capability, which will allow strike planners to select lower yields for existing targets to reduce collateral damage.

The B61–12 was initially intended to replace all of the United States' existing gravity bombs; however, this plan has since been modified and is now intended to consolidate four of the five legacy types (the B61–3, −4, −7, and −10) into one bomb, leaving the US stockpile with three types of B61 gravity bomb when completed (the B61–11, −12, and 13).

By the end of fiscal year 2023, the NNSA had reached the 65 percent completion milestone for B61–12 program's canned subassembly production and the 50 percent completion milestone for all remaining components (US Department of Energy (2024b, 2–8). The B61–12 became operational with the B-2 bombers in 2023 (National Nuclear Security Administration 2023) and fighter-bombers in 2024 (National Nuclear Security Administration 2024c). The bomb is in the process of being deployed to Europe (see below).

The United States was initially expected to produce approximately 480 B61–12 bombs, but in 2023, it announced that of these a small number will be produced as B61–13, a gravity bomb with a much larger yield (US Department of Defense 2023e). The B61–13 will use the warhead from B61-7s but will add the B61–12's safety and control features and guided tail kit for improved accuracy. As such, the B61–13 will have a maximum yield similar to that of the B61–7 with 360 kilotons—significantly higher than the B61–12's yield of 50 kilotons. The B61–13 will be designed for the future B-21 bomber and possibly the B-2 until the bomber's retirement. The military justification for the new B61–13 gravity bomb is difficult to identify through open sources, although it appears that the bomb will have a mission related to broad area targeting and perhaps holding some underground targets at risk.

The B61–13's development may also be related to the effort to retire the B83–1 (Kristensen and Korda 2023). The B83–1 has long been targeted for retirement due to its age, high yield, and redundancy in the US arsenal. As of November 2024, the bomb had not yet been formally removed from the stockpile, but we assess that it is no longer active and its formal retirement will take place within the next couple of months once the new Nuclear Weapons Stockpile Plan is signed by the President.

Nonstrategic nuclear weapons

The United States has only one type of nonstrategic nuclear weapon in its stockpile: the B61 gravity bomb. But it exists in several versions: the B61–3 and the B61–4 with yields varying from 0.3 kilotons up to 170 and 50 kilotons, respectively, and the new B61–12 entering the stockpile with a yield of up to 50 kilotons. All other previous versions have been retired and the B61–12 will eventually replace the −3 and −4 versions. Approximately 200 such tactical B61 bombs are currently stockpiled (see Table 1). About 100 of these (versions −3 and − 4) are thought to be deployed at six bases in five European countries: Aviano and Ghedi in Italy; Büchel in Germany; Incirlik in Turkey; Kleine Brogel in Belgium; and Volkel in the Netherlands. This number has declined since 2009 partly due to reduction of operational storage capacity at Aviano and Incirlik (Kristensen 2015). A seventh country—Greece—has a contingency nuclear strike mission and accompanying reserve squadron, but it does not host any nuclear weapons (Kristensen 2022b).

The other 100 B61 bombs are stored in the United States for backup and potential use by US fighter-bombers in support of allies outside Europe, including Northeast Asia. The fighter-bombers include F-15Es from the 391st Fighter Squadron of the 366th Fighter Wing at Mountain Home in Idaho (Carkhuff 2021).

Over the next few years, the new B61–12 will replace all legacy B61 bombs currently deployed in Europe and will be integrated onto US- and allied-operational tactical aircraft (Kristensen 2023). It is unclear as of the time of writing whether any B61-12s have shipped to Europe.

The Belgian, Dutch, German, and Italian air forces are currently assigned an active nuclear strike role with US nuclear weapons. Under normal circumstances, the nuclear weapons are kept under the control of US Air Force personnel; their use in war must be authorized by the US president. A 2022 NATO factsheet states that "a nuclear mission can only be undertaken after explicit political approval is given by NATO's Nuclear Planning Group authorization is received from the US President and UK prime minister" (NATO 2022).

All NATO allies that host US nuclear weapons—with the likely exception of Turkey—are acquiring the F-35A Lighting II for the continuation of their respective nuclear missions. Until then, Belgium and the Netherlands will continue to use the F-16, and Italy and Germany will continue to use the PA-200.

Incirlik Air Base in Turkey hosts an estimated 20 to 30 B61 nuclear bombs for delivery by US aircraft or, in a contingency, Turkish F-16 aircraft. Unlike other

NATO partners, Turkey does not allow the US to permanently base its aircraft at Incirlik; in a crisis, US aircraft would have to fly to the base to pick up the B61 bombs, or the bombs would have to be shipped out for use.

Despite the *New York Times* reporting in 2019 that US officials had reviewed emergency nuclear weapons evacuation plans for Incirlik (Sanger 2019), United States Air Force Europe A10 leaders visited Incirlik in July 2023 to discuss the "surety mission" and "the role that Incirlik plays in strategic deterrence," indicating that the nuclear mission at Incirlik is still in effect (Myricks 2023). ("Surety" is a term commonly used by the Pentagon and the Department of Energy to refer to the capability to keep nuclear weapons safe, secure, and under positive control, whereas the "A10 office" is the Air Force's office for "Strategic Deterrence and Nuclear Integration.") This is further reinforced by ongoing infrastructure work at nuclear weapon storage sites in Turkey (US Department of Defense 2022b).

The United States withdrew nuclear weapons from the United Kingdom around 2007 after storing them at Royal Air Force (RAF) Lakenheath for several decades (Kristensen 2008). But increasing evidence over the past two to three years suggests that the United States may be returning its nuclear mission to UK soil (Korda and Kristensen 2023).

In addition to the mention of the construction of a "surety dormitory" at RAF Lakenheath in USAF FY 2024 budget documents, *The Telegraph* in January 2024 described Pentagon contract documents that confirmed that the US Air Force intended to return the "nuclear mission" to the base (Diver 2024). It appears unlikely that the United States plans to permanently store nuclear weapons at RAF Lakenheath; however, it is clear that preparations are underway to reinstate the base's capability to receive nuclear weapons, possibly to give NATO the option to redistribute its nuclear weapons in times of heightened tensions, or to potentially move them out of Turkey in the future (see Figure 5).

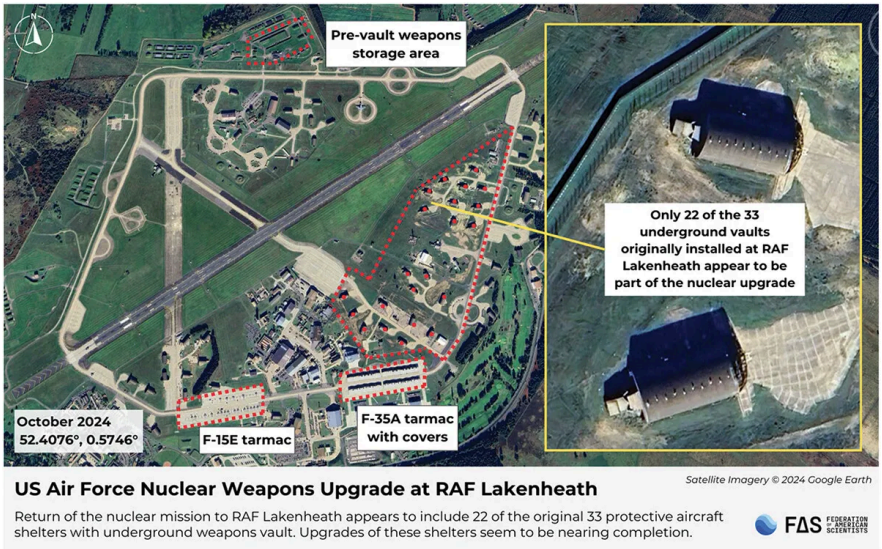

Figure 5. Upgrades at Royal Air Force Lakenheath, United Kingdom. Upgrades of nuclear weapons facilities at RAF Lakenheath are well underway. It appears that only 22 of 33 underground storage vaults built at the base are being upgraded. (Credit: Federation of American Scientists/Google Earth)

NATO Member States that do not host nuclear weapons can still participate in the nuclear mission as part of Conventional Support to Nuclear Operations (CSNO), previously known as Support of Nuclear Operations With Conventional Air Tactics, or SNOWCAT.

NATO is implementing a broad modernization of the nuclear posture in Europe that involves upgrading bombs, aircraft, and the weapons storage system (Kristensen 2022b). The tactical B61–12 is identical to the strategic B61–12 assigned to the B-2 (and soon B-21) bombers. The increased accuracy of the B61–12 will give the tactical bombs in Europe the same military capability as strategic bombs used by the bombers in the United States. Although the B61–12 has not been designed as a designated earth-penetrator like the B61–11, it does appear to have some limited earth-penetration capability that will increase the capability of the stockpile in Europe to hold at risk underground targets (Kristensen and McKinzie 2016). While the old PA-200 Tornado and F-16MLU

jets will not be able to make use of the increased accuracy provided by the B61–12 tail kit, the F-15E and new F-35A will.

The NNSA's FY 2025 Stockpile Stewardship and Management Plan, released in September 2024, indicated that the B61–12 had been formally assigned to the F-15, F-16, F-35, B-2, and "certified NATO aircraft," indicating that it had received certifications of compatibility with all of these aircraft (National Nuclear Security Administration 2024c, 1–4). Some of these allied aircraft trained with inert B61-12s throughout 2023 and 2024: for example, an unofficial photographer captured a Luftwaffe Tornado training at Edwards Air Base in September 2024 with a B61–12 on its central pylon (2024).

RAF Lakenheath was the first USAF base in Europe to receive the nuclear-capable F-35A fighter-bombers, followed by Volkel in the Netherlands (Korda and Kristensen 2023; Kristensen 2024c).

At the time of writing it remained unclear whether any B61-12s had been delivered to European bases.

In addition to weapons and aircraft, NATO's nuclear modernization involves life-extending the weapons storage security system, including upgrading command and control, as well as security, at the six active bases (Aviano, Büchel, Ghedi, Kleine Brogel, Incirlik, and Volkel), one additional base (RAF Lakenheath), and one training base (Ramstein). Specifically, these upgrades include the installation of double-fence security perimeters, modernizing the weapon storage and security systems and the alarm communication and display systems, and the operation of new secure transportation and maintenance system trucks (Kristensen 2021). Security upgrades now appear to have been completed at Aviano, Incirlik, and Volkel, and are underway at Ghedi, Kleine Brogel, and Büchel. A loading pad designed for US C-17 aircraft that transports nuclear weapons and service equipment is also being added at Kleine Brogel, Büchel, Ghedi, and Volkel (Kristensen 2024c).

In addition to the modernization of weapons, aircraft, and bases, NATO also appears to be increasing the profile of the dual-capable aircraft posture. For example, NATO is now publicly announcing its annual Steadfast Noon tactical nuclear weapons exercise. In October 2024, the two-week exercise involved the participation of 13 countries and more than 60 aircraft including fighter jets and US B-52 bombers (NATO 2024). Interestingly, Finland, a formally neutral country, also participated in the exercise only 18 months after it joined NATO (Kristensen 2024c).

Finally, in addition to these ongoing upgrades, the United States is also considering developing a new non-strategic nuclear sea-launched cruise missile (SLCM-N), which was proposed during the first Trump administration (US Department of Defense 2018, 55). The Biden administration sought to cancel the SLCM-N, noting that "[f]urther investment in developing SLCM-N would divert resources and focus from higher modernization priorities for the US nuclear enterprise and infrastructure, which is already stretched to capacity after decades of deferred investments. It would also impose operational challenges on the Navy" (US Office of Management and Budget 2022). This is because to carry nuclear weapons onboard, Navy crews would require specialized training and would need to adopt strict security protocols that could operationally hinder these multipurpose vessels (Woolf 2022). Additionally, deployed nuclear sea-launched cruise missiles would take the place of more flexible conventional munitions for vessels on patrol, thus incurring a substantial opportunity cost (Moulton 2022).

Despite the Biden administration's conclusions, however, Congress has forced the administration to establish the SLCM-N as a program of record. The Senate's FY25 NDAA would limit the Navy Secretary's travel funding until an SLCM-N program office has been established and staffed. The Bill additionally would require the establishment of a separate, dedicated program element for the development of the SLCM-N beginning with the President's FY2026 budget request (2024). The SLCM-N was originally expected to use the W80–4 warhead that is being developed for the LRSO (US Department of Energy 2024a); however, this is currently being renegotiated. The warhead and delivery platform are expected to be finalized in early 2025. If the SLCM-N does use an alteration of the W80–4, then the number of W80–4 warheads attributed to the LRSO would likely be reduced by a corresponding amount. As a result, it is possible that the US nuclear stockpile would not necessarily increase even if the SLCM-N was ultimately fielded. If the Trump administration

decides to produce additional W80–4 warheads or a new version, the SLCM-N could be delayed further and cost more.

Acknowledgments

The authors wish to thank Allie Maloney, the Herbert Scoville Jr. Peace Fellow for the Nuclear Information Project at the Federation of American Scientists, for her invaluable assistance with background research, analysis, and generation of graphics for this publication.

This research was carried out with generous contributions from the Carnegie Corporation of New York, the Jubitz Foundation, the New-Land Foundation, Ploughshares, the Prospect Hill Foundation, and individual donors.

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